

WHAT IS CLAIMED IS

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1. A distributed Bragg reflector,  
comprising:

a first semiconductor layer having a first,  
larger refractive index;

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a second semiconductor layer having a  
second refractive index, said first refractive index  
larger than said second refractive index, said first  
and second semiconductor layers being stacked  
alternately, and

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a material layer having a refractive index  
intermediate between said first and second refractive  
indices, having a thickness equal to or larger than 5  
nm but equal to or smaller than 50 nm, and having a  
third refractive index intermediate between said  
20 first and second refractive indices,

wherein said distributed Bragg reflector is  
tuned to a wavelength of 1.1  $\mu\text{m}$  or longer.

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2. A distributed Bragg reflector as claimed  
in claim 1, wherein said material layer has a  
thickness equal to or larger than 20 nm.

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3. A distributed Bragg reflector as claimed  
in claim 1, wherein said material layer has a  
10 thickness equal to or larger than 30 nm.

15 4. A distributed Bragg reflector as claimed  
in claim 2, wherein said first and second  
semiconductor layers are formed of any of AlAs, GaAs  
and AlGaAs, and wherein there is a difference of Al  
content of less than 80% between said first  
20 semiconductor layer and said second semiconductor  
layer.

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5. A distributed Bragg reflector as claimed  
in claim 3, wherein said first semiconductor layer  
and said second semiconductor layer are formed of any  
of AlAs, GaAs and AlGaAs, and wherein there is a  
5 difference of Al content of 80% or more between said  
first semiconductor layer and said second  
semiconductor layer.

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6. A distributed Bragg reflector,  
comprising:

a first semiconductor layer having a first  
15 refractive index;

a second semiconductor layer having a  
second refractive index, said first refractive index  
larger than said second refractive index, said first  
and second semiconductor layers being stacked  
20 alternately; and

a material layer having a third refractive  
index intermediate between said first and second  
refractive indices, said distributed Bragg reflector  
being tuned to a wavelength of 1.1  $\mu\text{m}$  or longer,  
25 said material layer having a thickness

smaller than  $(50\lambda - 15)$  (nm) where  $\lambda$  is a tuned wavelength of the distributed Bragg reflector.

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7. A distributed Bragg reflector as claimed in claim 6, wherein said material layer has a thickness of 20 nm or more.

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8. A distributed Bragg reflector as claimed in claim 6, wherein said material layer has a thickness of 30 nm or more.

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9. A distributed Bragg reflector, comprising:

a first semiconductor layer having a first bandgap;

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a second semiconductor layer having a

second bandgap, said first bandgap smaller than said second bandgap, said first and second semiconductor layers being stacked alternately; and

5 a material layer having a third bandgap intermediate between said first and second bandgaps, provided between said first and second semiconductor layer,

said material layer changing a valence band energy thereof in a thickness direction from said 10 first semiconductor layer to said second semiconductor layer,

said material layer comprising a first layer adjacent to said first semiconductor layer and a second layer adjacent to said second semiconductor 15 layer, and

said first layer and second layer having first and second rates of compositional change such that said first rate being larger than said second rate.

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10. A distributed Bragg reflector as  
25 claimed in claim 9, wherein said intermediate layer

changes said valence band energy continuously and gradually from said first semiconductor layer to said second semiconductor layer.

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11. A distributed Bragg reflector as claimed in claim 9, wherein said intermediate layer  
10 changes said valence band energy stepwise from said first semiconductor layer to said second semiconductor layer.

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12. A distributed Bragg reflector as claimed in claim 9, wherein said intermediate layer comprises a layer in which said valence band energy  
20 changes continuously and a layer in which said valence band energy changes stepwise.

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13. A distributed Bragg reflector as  
claimed in claim 9, wherein said first and second  
layers have respective first and second thicknesses,  
such that said first thickness is smaller than said  
5 second thickness.

10 14. A distributed Bragg reflector as  
claimed in claim 9, wherein there is a stepped change  
of valence band energy at an interface between said  
first semiconductor layer and said material layer.

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15. A distributed Bragg reflector as  
claimed in claim 9, wherein said first and second  
20 semiconductor layers comprise a material of AlGaAs  
system.

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16. A distributed Bragg reflector as claimed in claim 9, wherein said first and second semiconductor layers comprise a material of AlGaInP system.

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17. A distributed Bragg reflector as  
10 claimed in claim 9, wherein said first and second semiconductor layers and said intermediate layer have a carrier density of  $5 \times 10^{17} \text{cm}^{-3} - 2 \times 10^{18} \text{cm}^{-3}$ ,  
said intermediate layer has a thickness in the range of 5 - 40 nm, and said intermediate layer is  
15 characterized by an average change rate of Al content in the range of  $0.02 - 0.15 \text{ nm}^{-1}$ .

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18. A surface-emission laser diode,  
comprising:

an active layer; and

a resonator cooperating with said active  
25 layer, said active layer comprising upper and lower



reflectors disposed above and below said active layer,  
at least one of said upper and lower reflectors  
comprising a distributed Bragg reflector, comprising:

a first semiconductor layer having a first  
5 refractive index;

a second semiconductor layer having a  
second refractive index, said first refractive index  
larger than said second refractive index, said first  
and second semiconductor layers being stacked  
10 alternately; and

a material layer having a third refractive  
index intermediate between said first and second  
refractive indices, said distributed Bragg reflector  
being tuned to a wavelength of 1.1  $\mu\text{m}$  or longer,

15 said material layer having a thickness  
equal to or larger than 5 nm but equal to or smaller  
than 50 nm.

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19. A surface-emission laser diode as  
claimed in claim 18, wherein said material layer has  
a thickness equal to or larger than 20 nm.

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20. A surface-emission laser diode as  
claimed in claim 18, wherein said material layer has  
a thickness equal to or larger than 30 nm.

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21. A surface-emission laser diode as  
claimed in claim 19, wherein said first and second  
10 semiconductor layers are formed of any of AlAs, GaAs  
and AlGaAs, and wherein there is a difference of Al  
content of less than 80% between said first  
semiconductor layer and said second semiconductor  
layer.

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22. A surface-emission laser diode as  
20 claimed in claim 20, wherein said first semiconductor  
layer and said second semiconductor layer are formed  
of any of AlAs, GaAs and AlGaAs, and wherein there is  
a difference of Al content of 80% or more between  
said first semiconductor layer and said second  
25 semiconductor layer.

23. A surface-emission laser diode as  
claimed in claim 18, wherein said active layer is  
formed of any of a GaNAs layer, a GaInAs layer, a  
GaInNAS layer, a GaAsSb layer, a GaInAsSb layer, and  
5 a GaInNASb layer.

10 24. A surface-emission laser diode,  
comprising:  
an active layer; and  
a resonator cooperating with said active  
layer, said active layer comprising upper and lower  
15 reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
comprising:  
a first semiconductor layer having a first  
20 refractive index;  
a second semiconductor layer having a  
second refractive index, said first refractive index  
larger than said second refractive index, said first  
and second semiconductor layers being stacked  
25 alternately;

a material layer having a third refractive index intermediate between said first and second refractive indices, said distributed Bragg reflector being tuned to a wavelength of  $1.1 \mu\text{m}$  or longer,

5           said material layer having a thickness smaller than  $(50\lambda - 15)$  (nm) where  $\lambda$  is a tuned wavelength of the distributed Bragg reflector.

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25. A surface-emission laser diode as claimed in claim 24, wherein said material layer has a thickness of 20 nm or more.

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26. A surface-emission laser diode as  
20 claimed in claim 24, wherein said material layer has a thickness of 30 nm or more.

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27. A surface-emission laser diode as  
claimed in claim 24, wherein said active layer is  
formed of any of a GaNAs layer, a GaInAs layer, a  
GaInNAs layer, a GaAsSb layer, a GaInAsSb layer, and  
5 a GaInNAsSb layer.

10 28. A surface-emission laser diode,  
comprising:  
an active layer; and  
a resonator cooperating with said active  
layer, said active layer comprising upper and lower  
15 reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
comprising:  
a first semiconductor layer having a first  
20 bandgap;  
a second semiconductor layer having a  
second bandgap, said first bandgap smaller than said  
second bandgap, said first and second semiconductor  
layers being stacked alternately; and  
25 a material layer having a third bandgap

intermediate between said first and second bandgaps,  
provided between said first and second semiconductor  
layer,

5       said material layer changing a valence band  
energy thereof in a thickness direction from said  
first semiconductor layer to said second  
semiconductor layer,

10       said material layer comprising a first  
layer adjacent to said first semiconductor layer and  
a second layer adjacent to said second semiconductor  
layer, and

15       said first layer and second layer having  
first and second rates of compositional change such  
that said first rate being larger than said second  
rate.

20       29. A surface-emission laser diode as  
claimed in claim 28, wherein said intermediate layer  
changes said valence band energy continuously and  
gradually from said first semiconductor layer to said  
second semiconductor layer.

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30. A surface-emission laser diode as  
claimed in claim 28, wherein said intermediate layer  
changes said valence band energy stepwise from said  
first semiconductor layer to said second  
5 semiconductor layer.

31. A surface-emission laser diode as  
10 claimed in claim 28, wherein said intermediate layer  
comprises a layer in which said valence band energy  
changes continuously and a layer in which said  
valence band energy changes stepwise.

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32. A surface-emission laser diode as  
20 claimed in claim 28, wherein said first and second  
layers have respective first and second thicknesses,  
such that said first thickness is smaller than said  
second thickness.

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33. A surface-emission laser diode as  
claimed in claim 28, wherein there is a stepped  
change of valence band energy at an interface between  
said first semiconductor layer and said material  
5 layer.

10 34. A surface-emission laser diode as  
claimed in claim 28, wherein said first and second  
semiconductor layers comprise a material of AlGaAs  
system.

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35. A surface-emission laser diode as  
claimed in claim 28, wherein said first and second  
20 semiconductor layers comprise a material of AlGaInP  
system.

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36. A surface-emission laser diode as  
claimed in claim 28, wherein said first and second  
semiconductor layers and said intermediate layer have  
a carrier density of  $5 \times 10^{17} \text{cm}^{-3} - 2 \times 10^{18} \text{cm}^{-3}$ , and  
5 wherein said intermediate layer has a thickness in  
the range of 5 - 40 nm, and wherein said intermediate  
layer is characterized by an average change rate of  
Al content in the range of 0.02 - 0.15 nm<sup>-1</sup>.

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37. A laser diode array, comprising:  
a substrate; and  
15 a plurality of surface-emission laser  
diodes formed commonly on said substrate, each of  
said plurality of surface-emission laser diodes  
comprising:  
an active layer; and  
20 a resonator cooperating with said active  
layer, said active layer comprising upper and lower  
reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
25 comprising:

a first semiconductor layer having a first refractive index;

a second semiconductor layer having a second refractive index, said first refractive index  
5 larger than said second refractive index, said first and second semiconductor layers being stacked alternately; and

a material layer having a third refractive index intermediate between said first and second  
10 refractive indices, said distributed Bragg reflector being tuned to a wavelength of 1.1  $\mu\text{m}$  or longer,

said material layer having a thickness equal to or larger than 5 nm but equal to or smaller than 50 nm.

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38. A laser diode array, comprising:

20 a substrate; and

a plurality of surface-emission laser diodes formed commonly on said substrate, each of said surface emission laser diodes comprising:

an active layer; and

25 a resonator cooperating with said active

layer, said active layer comprising upper and lower reflectors disposed above and below said active layer,

at least one of said upper and lower reflectors comprising a distributed Bragg reflector,

5 comprising:

a first semiconductor layer having a first refractive index;

a second semiconductor layer having a second refractive index, said first refractive index  
10 larger than said second refractive index, said first and second semiconductor layers being stacked alternately; and

a material layer having a third refractive index intermediate between said first and second  
15 refractive indices, said distributed Bragg reflector being tuned to a wavelength of  $1.1 \mu\text{m}$  or longer,

said material layer having a thickness smaller than  $(50\lambda - 15)$  (nm) where  $\lambda$  is a tuned wavelength of the distributed Bragg reflector.

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39. A surface-emission laser diode array,

25 comprising:

a substrate; and  
a plurality of laser diodes, each of said  
surface-emission laser diodes, comprising:  
an active layer; and  
5 a resonator cooperating with said active  
layer, said active layer comprising upper and lower  
reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
10 comprising:  
a first semiconductor layer having a first  
bandgap;  
a second semiconductor layer having a  
second bandgap, said first bandgap smaller than said  
15 second bandgap, said first and second semiconductor  
layers being stacked alternately; and  
a material layer having a third bandgap  
intermediate between said first and second bandgaps,  
provided between said first and second semiconductor  
20 layer,  
said material layer changing a valence band  
energy thereof in a thickness direction from said  
first semiconductor layer to said second  
semiconductor layer,  
25 said material layer comprising a first

layer adjacent to said first semiconductor layer and  
a second layer adjacent to said second semiconductor  
layer, and

5       said first layer and second layer having  
first and second rates of compositional change such  
that said first rate being larger than said second  
rate.

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40. An optical interconnection system,  
comprising:

15       a surface-emission laser diode; and  
an optical transmission path coupled  
optically to said surface-emission laser diode,  
said surface-emission laser diode

comprising:

20       an active layer; and  
a resonator cooperating with said active  
layer, said active layer comprising upper and lower  
reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
25       comprising:

a first semiconductor layer having a first refractive index;

a second semiconductor layer having a second refractive index, said first refractive index  
5 larger than said second refractive index, said first and second semiconductor layers being stacked alternately; and

a material layer having a third refractive index intermediate between said first and second  
10 refractive indices,

said distributed Bragg reflector being tuned to a wavelength of 1.1  $\mu\text{m}$  or longer, and

said material layer having a thickness equal to or larger than 5 nm but equal to or smaller  
15 than 50 nm.

20 41. An optical interconnection system, comprising:

a surface-emission laser diode; and  
an optical transmission path coupled optically to said surface-emission laser diode,  
25 said surface-emission laser diode

comprising:

an active layer; and

a resonator cooperating with said active layer, said active layer comprising upper and lower reflectors disposed above and below said active layer,  
5 at least one of said upper and lower reflectors comprising a distributed Bragg reflector, comprising:

a first semiconductor layer having a first  
10 refractive index;

a second semiconductor layer having a second refractive index, said first refractive index larger than said second refractive index, said first and second semiconductor layers being stacked  
15 alternately; and

a material layer having a third refractive index intermediate between said first and second refractive indices, and

wherein there is provided a material layer  
20 having a refractive index intermediate between said first refractive index and said second refractive index,

said material layer having a thickness smaller than  $(50\lambda - 15)$  (nm) where  $\lambda$  is a tuned  
25 wavelength of the distributed Bragg reflector.

42. An optical interconnection system,  
comprising:  
a surface-emission laser diode; and  
an optical transmission path coupled  
5 optically to said surface-emission laser diode,  
said surface-emission laser diode  
comprising:  
an active layer; and  
a resonator cooperating with said active  
10 layer, said active layer comprising upper and lower  
reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
comprising:  
15 a first semiconductor layer having a first  
bandgap;  
a second semiconductor layer having a  
second bandgap, said first bandgap smaller than said  
second bandgap, said first and second semiconductor  
20 layers being stacked alternately; and  
a material layer having a third bandgap  
intermediate between said first and second bandgaps,  
provided between said first and second semiconductor  
layer,  
25 said material layer changing a valence band



energy thereof in a thickness direction from said first semiconductor layer to said second semiconductor layer, and

said material layer comprising a first layer adjacent to said first semiconductor layer and a second layer adjacent to said second semiconductor layer,

said first layer and second layer having first and second rates of compositional change such that said first rate being larger than said second rate.

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43. An optical interconnection system, comprising:

a surface-emission laser diode array comprising a substrate and a plurality of surface-emission laser diodes provided commonly on said substrate; and

an optical transmission path coupled optically to each of said plurality of surface-emission laser diodes,

each of said plurality of surface-emission

laser diodes comprising:

an active layer; and

a resonator cooperating with said active layer, said active layer comprising upper and lower  
5 reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
comprising:

a first semiconductor layer having a first  
10 refractive index;

a second semiconductor layer having a  
second refractive index, said first refractive index  
larger than said second refractive index, said first  
and second semiconductor layers being stacked  
15 alternately; and

a material layer having a third refractive  
index intermediate between said first and second  
refractive indices,

said distributed Bragg reflector being  
20 tuned to a wavelength of  $1.1\ \mu\text{m}$  or longer, and

said material layer having a thickness  
equal to or larger than 5 nm but equal to or smaller  
than 50 nm.

44. An optical interconnection system,  
comprising:

a surface-emission laser diode array  
comprising a substrate and a plurality of surface-  
5 emission laser diodes formed commonly on said  
substrate; and

an optical transmission path coupled  
optically to each of said plurality of surface-  
emission laser diodes,

10 each of said surface-emission laser diodes  
comprising:

an active layer; and

a resonator cooperating with said active  
layer, said active layer comprising upper and lower  
15 reflectors disposed above and below said active layer,

at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
comprising:

a first semiconductor layer having a first  
20 refractive index;

a second semiconductor layer having a  
second refractive index, said first refractive index  
larger than said second refractive index, said first  
and second semiconductor layers being stacked  
25 alternately; and

a material layer having a third refractive index intermediate between said first and second refractive indices,

said distributed Bragg reflector being  
5 tuned to a wavelength of  $1.1 \mu\text{m}$  or longer,

said material layer having a thickness smaller than  $(50\lambda - 15)$  [nm] where  $\lambda$  is a tuned wavelength of the distributed Bragg reflector.

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45. An optical interconnection system, comprising:

15 a surface-emission laser diode array comprising a plurality of surface-emission laser diodes; and

an optical transmission path coupled optically to each of said plurality of surface-  
20 emission laser diodes,

each of said surface-emission laser diodes comprising:

an active layer; and

a resonator cooperating with said active  
25 layer, said active layer comprising upper and lower

reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
comprising:

5 a first semiconductor layer having a first  
bandgap;

a second semiconductor layer having a  
second bandgap, said first bandgap smaller than said  
second bandgap, said first and second semiconductor  
10 layers being stacked alternately; and

a material layer having a third bandgap  
intermediate between said first and second bandgaps,  
provided between said first and second semiconductor  
layer,

15 said material layer changing a valence band  
energy thereof in a thickness direction from said  
first semiconductor layer to said second  
semiconductor layer,

said material layer comprising a first  
20 layer adjacent to said first semiconductor layer and  
a second layer adjacent to said second semiconductor  
layer, and

said first layer and second layer having  
first and second rates of compositional change such  
25 that said first rate being larger than said second

rate.

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46. An optical telecommunication system,  
comprising:

a surface-emission laser diode; and  
an optical transmission path coupled  
10 optically to said surface-emission laser diode,  
said surface-emission laser diode

comprising:

an active layer; and  
a resonator cooperating with said active  
15 layer, said active layer comprising upper and lower  
reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
comprising:

20 a first semiconductor layer having a first  
refractive index;

a second semiconductor layer having a  
second refractive index, said first refractive index  
larger than said second refractive index, said first  
25 and second semiconductor layers being stacked

alternately; and

a material layer having a third refractive index intermediate between said first and second refractive indices,

5           said distributed Bragg reflector being tuned to a wavelength of  $1.1 \mu\text{m}$  or longer, and

          said material layer having a thickness equal to or larger than 5 nm but equal to or smaller than 50 nm.

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47. An optical telecommunication system,  
15 comprising:

a surface-emission laser diode; and  
an optical transmission path coupled optically to said surface-emission laser diode,  
said surface-emission laser diode

20 comprising:

an active layer; and  
a resonator cooperating with said active layer, said active layer comprising upper and lower reflectors disposed above and below said active layer,  
25 at least one of said upper and lower

reflectors comprising a distributed Bragg reflector,  
comprising:

a first semiconductor layer having a first  
refractive index;

5 a second semiconductor layer having a  
second refractive index, said first refractive index  
larger than said second refractive index, said first  
and second semiconductor layers being stacked  
alternately; and

10 a material layer having a third refractive  
index intermediate between said first and second  
refractive indices,

said distributed Bragg reflector being  
tuned to a wavelength of  $1.1 \mu\text{m}$  or longer, and

15 said material layer having a thickness  
smaller than  $(50\lambda - 15)$  [nm] where  $\lambda$  is a tuned  
wavelength of the distributed Bragg reflector.

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48. An optical telecommunication system,  
comprising:

a surface-emission laser diode; and

25 an optical transmission path coupled



optically to said surface-emission laser diode,  
said surface-emission laser diode  
comprising:

an active layer; and

5 a resonator cooperating with said active  
layer, said active layer comprising upper and lower  
reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
10 comprising:

a first semiconductor layer having a first  
bandgap;

a second semiconductor layer having a  
second bandgap, said first bandgap smaller than said  
15 second bandgap, said first and second semiconductor  
layers being stacked alternately; and

a material layer having a third bandgap  
intermediate between said first and second bandgaps,  
provided between said first and second semiconductor  
20 layer,

said material layer changing a valence band  
energy thereof in a thickness direction from said  
first semiconductor layer to said second  
semiconductor layer,

25 said material layer comprising a first

layer adjacent to said first semiconductor layer and  
a second layer adjacent to said second semiconductor  
layer, and

5       said first layer and second layer having  
first and second rates of compositional change such  
that said first rate being larger than said second  
rate.

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49. An optical telecommunication system,  
comprising:

15       a surface-emission laser diode array  
comprising a substrate and a plurality of surface-  
emission laser diodes provided commonly on said  
substrate; and

20       an optical transmission path coupled  
optically to each of said plurality of surface-  
emission laser diodes,

      each of said plurality of surface-emission  
laser diodes comprising:

      an active layer; and

25       a resonator cooperating with said active  
layer, said active layer comprising upper and lower

reflectors disposed above and below said active layer,  
at least one of said upper and lower  
reflectors comprising a distributed Bragg reflector,  
comprising:

5                   a first semiconductor layer having a first  
refractive index;

                  a second semiconductor layer having a  
second refractive index, said first refractive index  
larger than said second refractive index, said first  
10 and second semiconductor layers being stacked  
alternately; and

                  a material layer having a third refractive  
index intermediate between said first and second  
refractive indices,

15                   said distributed Bragg reflector being  
tuned to a wavelength of  $1.1 \mu\text{m}$  or longer, and

                  said material layer having a thickness  
equal to or larger than 5 nm but equal to or smaller  
than 50 nm.

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50. An optical telecommunication system,  
25 comprising:

a surface-emission laser diode array comprising a substrate and a plurality of surface-emission laser diodes formed commonly on said substrate; and

5 an optical transmission path coupled optically to each of said plurality of surface-emission laser diodes,

each of said surface-emission laser diodes comprising:

10 an active layer; and

a resonator cooperating with said active layer, said active layer comprising upper and lower reflectors disposed above and below said active layer, at least one of said upper and lower

15 reflectors comprising a distributed Bragg reflector, comprising:

a first semiconductor layer having a first refractive index;

20 a second semiconductor layer having a second refractive index, said first refractive index larger than said second refractive index, said first and second semiconductor layers being stacked alternately; and

a material layer having a third refractive index intermediate between said first and second

25

refractive indices,

said distributed Bragg reflector being  
tuned to a wavelength of  $1.1 \mu\text{m}$  or longer, and

said material layer having a thickness  
5 smaller than  $(50\lambda - 15)$  (nm) where  $\lambda$  is a tuned  
wavelength of the distributed Bragg reflector.

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51. An optical telecommunication system,  
comprising:

a surface-emission laser diode array  
comprising a plurality of surface-emission laser  
15 diodes; and

an optical transmission path coupled  
optically to each of said plurality of surface-  
emission laser diodes,

each of said surface-emission laser diodes  
20 comprising:

an active layer; and

a resonator cooperating with said active  
layer, said active layer comprising upper and lower  
reflectors disposed above and below said active layer,  
25 at least one of said upper and lower

reflectors comprising a distributed Bragg reflector,  
comprising:

a first semiconductor layer having a first  
bandgap;

5 a second semiconductor layer having a  
second bandgap, said first bandgap smaller than said  
second bandgap, said first and second semiconductor  
layers being stacked alternately; and

a material layer having a third bandgap  
10 intermediate between said first and second bandgaps,  
provided between said first and second semiconductor  
layer,

said material layer changing a valence band  
energy thereof in a thickness direction from said  
15 first semiconductor layer to said second  
semiconductor layer,

said material layer comprising a first  
layer adjacent to said first semiconductor layer and  
a second layer adjacent to said second semiconductor  
20 layer,

said first layer and second layer having  
first and second rates of compositional change such  
that said first rate being larger than said second  
rate.

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52. An optical transmission/reception system, comprising:

an optical source formed of a surface-emission laser diode device, said surface-emission laser diode comprising: an active layer of any of a layer containing Ga, In, N and As as major constituent elements thereof and a layer containing Ga, In and As as major constituent elements thereof, said active layer producing optical radiation with a laser oscillation wavelength of  $1.1 - 1.7 \mu\text{m}$ ; and a cavity structure comprising a pair of reflectors provided above and below said active layer, each of said reflectors forming a semiconductor distributed Bragg reflector reflecting optical radiation having a wavelength of  $1.1 \mu\text{m}$  or more and comprising an alternate and repetitive stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x \leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x \leq 1$ ), wherein there is provided a hetero spike buffer layer between said first material layer and said second material layer, said hetero spike buffer layer having a refractive index intermediate between a refractive index of said first material layer and a refractive index of said second material layer, said hetero spike buffer layer having a composition represented as  $\text{Al}_z\text{Ga}_{1-z}\text{As}$  ( $0 \leq$

$y < z < x \leq 1$ ) and a thickness of 20 - 50 nm;

an optical fiber transmission path having  
an end coupled optically to said optical source; and

a photodetection unit coupled to the other  
5 end of said optical fiber transmission path,

said optical fiber transmission path being  
bent between a point A, in which said optical source  
is provided, and a point B, in which said  
photodetection unit is provided, such that there is  
10 no localized angle formed in said optical fiber  
transmission path.

15

53. An optical transmission/reception  
system, comprising:

an optical source formed of a surface-  
emission laser diode device, said surface-emission  
20 laser diode comprising: an active layer of any of a  
layer containing Ga, In, N and As as major  
constituent elements thereof and a layer containing  
Ga, In and As as major constituent elements thereof,  
said active layer producing optical radiation with a  
25 laser oscillation wavelength of 1.1 - 1.7  $\mu\text{m}$ ; and a



cavity structure comprising a pair of reflectors provided above and below said active layer, each of said reflectors forming a semiconductor distributed Bragg reflector reflecting optical radiation having a wavelength of  $1.1\mu\text{m}$  or more and comprising an alternate and repetitive stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x \leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x \leq 1$ ), wherein there is provided a hetero spike buffer layer between said first material layer and said second material layer, said hetero spike buffer layer having a refractive index intermediate between a refractive index of said first material layer and a refractive index of said second material layer, said hetero spike buffer layer having a composition represented as  $\text{Al}_z\text{Ga}_{1-z}\text{As}$  ( $0 \leq y < z < x \leq 1$ ) and a thickness of 20 - 50 nm;

an optical fiber transmission path having an end coupled to said optical source;

a photodetection unit coupled to another end of said optical fiber transmission path; and

a mirror provided between a point A, in which said optical source is provided, and a point B, in which said photodetection unit is provided, said mirror changing a direction of propagation of an optical signal transmitted through said optical fiber

transmission path.

5

54. An optical transmission/reception system for use in an apparatus, comprising:

an apparatus body;

10 a surface-emission laser diode device provided in said apparatus body as a laser optical source, said laser optical source producing an optical signal;

15 a photodetection unit provided in said apparatus body, said photodetection unit receiving said optical signal;

a cover member covering a light emitting part of said laser optical source; and

another cover member covering a photodetection part of said photodetection unit,

20 said surface-emission laser diode comprising: an active layer of any of a layer containing Ga, In, N and As as major constituent elements thereof and a layer containing Ga, In and As as major constituent elements thereof, said active  
25 layer producing optical radiation with a laser

oscillation wavelength of  $1.1 - 1.7 \mu\text{m}$ ; and a cavity structure comprising a pair of reflectors provided above and below said active layer, each of said reflectors forming a semiconductor distributed Bragg reflector reflecting optical radiation having a wavelength of  $1.1 \mu\text{m}$  or more and comprising an alternate and repetitive stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x \leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x \leq 1$ ), wherein there is provided a hetero spike buffer layer between said first material layer and said second material layer, said hetero spike buffer layer having a refractive index intermediate between a refractive index of said first material layer and a refractive index of said second material layer, said hetero spike buffer layer having a composition represented as  $\text{Al}_z\text{Ga}_{1-z}\text{As}$  ( $0 \leq y < z < x \leq 1$ ) and a thickness of  $20 - 50 \text{ nm}$ .

20

55. An optical telecommunication system, comprising:

a laser diode;  
a first optical fiber coupled optically to

25

said laser diode, said first optical fiber being injected with a laser beam produced by said laser diode;

a second optical fiber coupled optically to  
5. said first optical fiber, said second optical fiber being injected with an optical signal transmitted through said first optical fiber;

a third optical fiber coupled optically to  
said second optical fiber, said third optical fiber  
10 being injected with an optical signal transmitted through said second optical fiber; and

a photodetector coupled optically to said third optical fiber, said photodetector detecting an optical signal transmitted through said third optical  
15 fiber,

said laser diode comprising a surface-emission laser diode chip and comprising: an active layer of any of a layer containing Ga, In, N and As as major constituent elements thereof and a layer  
20 containing Ga, In and As as major constituent elements thereof, said active layer producing optical radiation with a laser oscillation wavelength of 1.1 - 1.7  $\mu\text{m}$ ; and a cavity structure comprising a pair of reflectors provided above and below said active  
25 layer, each of said reflectors forming a

semiconductor distributed Bragg reflector reflecting optical radiation having a wavelength of  $1.1\mu\text{m}$  or more and comprising an alternate and repetitive stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x \leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x \leq 1$ ), wherein there is provided a hetero spike buffer layer between said first material layer and said second material layer, said hetero spike buffer layer having a refractive index intermediate between a refractive index of said first material layer and a refractive index of said second material layer, said hetero spike buffer layer having a composition represented as  $\text{Al}_z\text{Ga}_{1-z}\text{As}$  ( $0 \leq y < z < x \leq 1$ ) and a thickness of 20 - 50 nm.

15

56. An optical telecommunication system, comprising:  
a laser diode;  
a first optical fiber coupled optically to said laser diode, said first optical fiber being injected with a laser beam produced by said laser diode;

25

a second optical fiber coupled optically to said first optical fiber, said second optical fiber being injected with an optical signal transmitted through said first optical fiber;

5 a third optical fiber coupled optically to said second optical fiber, said third optical fiber being injected with an optical signal transmitted through said second optical fiber,

said laser diode comprising a surface-emission laser diode chip and comprising: an active layer of any of a layer containing Ga, In, N and As as major constituent elements thereof and a layer containing Ga, In and As as major constituent elements thereof, said active layer producing optical  
10 radiation with a laser oscillation wavelength of 1.1 - 1.7  $\mu\text{m}$ ; and a cavity structure comprising a pair of reflectors provided above and below said active layer, each of said reflectors forming a semiconductor distributed Bragg reflector reflecting  
15 optical radiation having a wavelength of 1.1  $\mu\text{m}$  or more and comprising an alternate and repetitive stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x \leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x \leq 1$ ), wherein there is provided a hetero spike buffer  
20 layer between said first material layer and said  
25

second material layer, said hetero spike buffer layer  
having a refractive index intermediate between a  
refractive index of said first material layer and a  
refractive index of said second material layer, said  
5 hetero spike buffer layer having a composition  
represented as  $\text{Al}_z\text{Ga}_{1-z}\text{As}$  ( $0 \leq z < x \leq 1$ ) and a  
thickness of 20 - 50 nm,

said first optical fiber having a length of  
1 mm or more.

10

57. An optical telecommunication system  
15 comprising:

a laser diode; and

an optical transmission path coupled  
optically to said laser diode,

said laser diode comprising a surface-  
20 emission laser diode chip and comprising: an active  
layer of any of a layer containing Ga, In, N and As  
as major constituent elements thereof and a layer  
containing Ga, In and As as major constituent  
elements thereof, said active layer producing optical  
25 radiation with a laser oscillation wavelength of 1.1

- 1.7  $\mu\text{m}$ ; and a cavity structure comprising a pair of reflectors provided above and below said active layer, each of said reflectors forming a semiconductor distributed Bragg reflector reflecting  
5 optical radiation having a wavelength of 1.1  $\mu\text{m}$  or more and comprising an alternate and repetitive stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x \leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x \leq 1$ ), wherein there is provided a hetero spike buffer  
10 layer between said first material layer and said second material layer, said hetero spike buffer layer having a refractive index intermediate between a refractive index of said first material layer and a refractive index of said second material layer, said  
15 hetero spike buffer layer having a composition represented as  $\text{Al}_z\text{Ga}_{1-z}\text{As}$  ( $0 \leq y < z < x \leq 1$ ) and a thickness of 20 - 50 nm,

said optical transmission path comprising an optical fiber having a length L, said optical  
20 fiber including a core having a diameter D and a clad, wherein there holds a relationship  
$$10^5 \leq L/D \leq 10^9.$$



58. An optical telecommunication system,  
comprising:

a laser diode,

a mount substrate on which said laser diode  
5 is mounted;

said laser diode comprising a surface-  
emission laser diode chip and comprising: an active  
layer of any of a layer containing Ga, In, N and As  
as major constituent elements thereof and a layer  
10 containing Ga, In and As as major constituent  
elements thereof, said active layer producing optical  
radiation with a laser oscillation wavelength of 1.1  
- 1.7  $\mu\text{m}$ ; and a cavity structure comprising a pair  
of reflectors provided above and below said active  
15 layer, each of said reflectors forming a  
semiconductor distributed Bragg reflector reflecting  
optical radiation having a wavelength of 1.1  $\mu\text{m}$  or  
more and comprising an alternate and repetitive  
stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x$   
20  $\leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x$   
 $\leq 1$ ), wherein there is provided a hetero spike buffer  
layer between said first material layer and said  
second material layer, said hetero spike buffer layer  
having a refractive index intermediate between a  
25 refractive index of said first material layer and a

refractive index of said second material layer, said hetero spike buffer layer having a composition represented as  $\text{Al}_y\text{Ga}_{1-z}\text{As}$  ( $0 \leq y < z < x \leq 1$ ) and a thickness of 20 - 50 nm,

5. wherein a difference of linear thermal expansion coefficient between said laser diode and said substrate is within  $2 \times 10^{-6}/\text{K}$ .

10

59. An optical telecommunication system, comprising:

a laser diode; and

- 15 an optical fiber coupled optically to said laser diode,

said laser diode comprising a surface-emission laser diode chip and comprising: an active layer of any of a layer containing Ga, In, N and As as major constituent elements thereof and a layer containing Ga, In and As as major constituent elements thereof, said active layer producing optical radiation with a laser oscillation wavelength of 1.1 - 1.7  $\mu\text{m}$ ; and a cavity structure comprising a pair  
25 of reflectors provided above and below said active

layer, each of said reflectors forming a semiconductor distributed Bragg reflector reflecting optical radiation having a wavelength of  $1.1\mu\text{m}$  or more and comprising an alternate and repetitive

5 stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x \leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x \leq 1$ ), wherein there is provided a hetero spike buffer layer between said first material layer and said second material layer, said hetero spike buffer layer

10 having a refractive index intermediate between a refractive index of said first material layer and a refractive index of said second material layer, said hetero spike buffer layer having a composition represented as  $\text{Al}_z\text{Ga}_{1-z}\text{As}$  ( $0 \leq y < z < x \leq 1$ ) and a

15 thickness of 20 - 50 nm,

wherein said optical fiber is mechanically connected to said laser diode in the state that said optical fiber is urged in an axial direction thereof toward a light emitting part of said laser diode.

20

60. An optical telecommunication system,

25 comprising:

a laser diode; and  
one of an optical fiber and an optical waveguide coupled optically to said laser diode,  
said laser diode comprising a surface-  
5 emission laser diode chip and comprising: an active layer of any of a layer containing Ga, In, N and As as major constituent elements thereof and a layer containing Ga, In and As as major constituent elements thereof, said active layer producing optical  
10 radiation with a laser oscillation wavelength of 1.1 - 1.7  $\mu\text{m}$ ; and a cavity structure comprising a pair of reflectors provided above and below said active layer, each of said reflectors forming a semiconductor distributed Bragg reflector reflecting  
15 optical radiation having a wavelength of 1.1  $\mu\text{m}$  or more and comprising an alternate and repetitive stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x \leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x \leq 1$ ), wherein there is provided a hetero spike buffer  
20 layer between said first material layer and said second material layer, said hetero spike buffer layer having a refractive index intermediate between a refractive index of said first material layer and a refractive index of said second material layer, said  
25 hetero spike buffer layer having a composition

represented as  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x \leq 1$ ) and a thickness of 20 - 50 nm,

said optical fiber or said optical waveguide having a core with a diameter  $x$ , said laser diode having an aperture  $d$  and an optical emission angle  $\theta$ ,

wherein there holds a relationship

$$d + 2l \tan(\theta/2) \leq x,$$

where  $l$  represents an optical path length from said laser diode to an edge of said optical fiber or optical waveguide.

15

61. An optical telecommunication system, comprising:

a laser diode; and

an optical waveguide coupled optically to said laser diode,

said laser diode comprising a surface-emission laser diode chip and comprising: an active layer of any of a layer containing Ga, In, N and As as major constituent elements thereof and a layer containing Ga, In and As as major constituent

elements thereof, said active layer producing optical radiation with a laser oscillation wavelength of 1.1 - 1.7  $\mu\text{m}$ ; and a cavity structure comprising a pair of reflectors provided above and below said active layer, each of said reflectors forming a semiconductor distributed Bragg reflector reflecting optical radiation having a wavelength of 1.1  $\mu\text{m}$  or more and comprising an alternate and repetitive stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x \leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x \leq 1$ ), wherein there is provided a hetero spike buffer layer between said first material layer and said second material layer, said hetero spike buffer layer having a refractive index intermediate between a refractive index of said first material layer and a refractive index of said second material layer, said hetero spike buffer layer having a composition represented as  $\text{Al}_z\text{Ga}_{1-z}\text{As}$  ( $0 \leq y < z < x \leq 1$ ) and a thickness of 20 - 50 nm,

wherein there holds a relationship

$$0.5 \leq F/d \leq 2$$

where d represents a diameter of a circle touching internally to an optical emission part of said laser diode and F represents a core diameter of said optical fiber.

62. An optical telecommunication system,  
comprising:

a laser diode; and

an optical waveguide coupled optically to a  
5 laser chip,

said laser diode comprising a surface-  
emission laser diode chip and comprising: an active  
layer of any of a layer containing Ga, In, N and As  
as major constituent elements thereof and a layer  
10 containing Ga, In and As as major constituent  
elements thereof, said active layer producing optical  
radiation with a laser oscillation wavelength of 1.1  
- 1.7  $\mu\text{m}$ ; and a cavity structure comprising a pair  
of reflectors provided above and below said active  
15 layer, each of said reflectors forming a  
semiconductor distributed Bragg reflector reflecting  
optical radiation having a wavelength of 1.1  $\mu\text{m}$  or  
more and comprising an alternate and repetitive  
stacking of a first material layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  ( $0 < x$   
20  $\leq 1$ ) and a second material layer of  $\text{Al}_y\text{Ga}_{1-y}\text{As}$  ( $0 \leq y < x$   
 $\leq 1$ ), wherein there is provided a hetero spike buffer  
layer between said first material layer and said  
second material layer, said hetero spike buffer layer  
having a refractive index intermediate between a  
25 refractive index of said first material layer and a

refractive index of said second material layer, said hetero spike buffer layer having a composition represented as  $\text{Al}_y\text{Ga}_{1-z}\text{As}$  ( $0 \leq y < z < x \leq 1$ ) and a thickness of 20 - 50 nm,

5                   said laser diode including an optical emission part having an area  $S \text{ [mm}^2\text{]}$ , said laser diode being driven with an operational voltage  $V \text{ [volts]}$ ,

                  wherein a parameter  $V/S$  falls in a range  
10   from 15000 to 30000.

15                   63. A semiconductor distributed Bragg reflector comprising:

                  an alternate stacking of first and second semiconductor layers having respective, different refractive indices; and

20                   a plurality of intermediate layers each sandwiched between a first semiconductor layer and a second semiconductor layer, said intermediate layer having a refractive index intermediate between said refractive indices of said first and second  
25   semiconductor layers,



an intermediate layer provided in a region  
of said semiconductor distributed Bragg reflector  
having a thickness different from an intermediate  
layer provided in a different region of said  
5 semiconductor distributed Bragg reflector.

10 64. The semiconductor distributed Bragg  
reflector as claimed in claim 63, wherein a  
difference of bandgap between said first and second  
semiconductor layers is set smaller in a region of  
said semiconductor distributed Bragg reflector where  
15 said intermediate layer has an increased thickness  
than in a region of said distributed Bragg reflector  
where said intermediate layer has a reduced thickness.

20

65. The semiconductor distributed Bragg  
reflector as claimed in claim 63, wherein said  
intermediate layers have different thickness and  
25 different doping concentrations within said

semiconductor distributed Bragg reflector, said thickness and doping concentration being changed in correspondence to electric field strength of light within said semiconductor distributed Bragg reflector.

5

66. The semiconductor distributed Bragg reflector as claimed in claim 65, wherein said intermediate layer has an increased thickness and reduced impurity doping concentration in a region of said semiconductor distributed Bragg reflector where the electric field strength of light is large, and wherein said intermediate layer is formed to have a reduced thickness and increased impurity doping concentration in a region of said semiconductor distributed Bragg reflector where the electric field strength of light is small.

20

67. The semiconductor distributed Bragg reflector as claimed in claim 63, wherein said

25

semiconductor distributed Bragg reflector has a design reflection wavelength of  $1.1\mu\text{m}$  or longer.

5

68. A surface-emission laser diode having a semiconductor distributed Bragg reflector, said semiconductor distributed Bragg reflector comprising:

10           an alternate stacking of first and second semiconductor layers having respective, different refractive indices; and

                  a plurality of intermediate layers each sandwiched between a first semiconductor layer and a  
15   second semiconductor layer, said intermediate layer having a refractive index intermediate between said refractive indices of said first and second semiconductor layers,

                  an intermediate layer provided in a region  
20   of said semiconductor distributed Bragg reflector having a thickness different from an intermediate layer provided in a different region of said semiconductor distributed Bragg reflector.

25

69. The surface-emission laser diode as  
claimed in claim 68, wherein a difference of bandgap  
between said first and second semiconductor layers is  
set smaller in a region of said semiconductor  
5 distributed Bragg reflector where said intermediate  
layer has an increased thickness than in a region of  
said distributed Bragg reflector where said  
intermediate layer has a reduced thickness.

10

70. The surface-emission laser diode as  
claimed in claim 68, wherein said intermediate layers  
15 have different thickness and different doping  
concentrations within said semiconductor distributed  
Bragg reflector, said thickness and doping  
concentration being changed in correspondence to  
electric field strength of light within said  
20 semiconductor distributed Bragg reflector.

25

71. The surface-emission laser diode as

claimed in claim 68, wherein said intermediate layer  
has an increased thickness and reduced impurity  
doping concentration in a region of said  
semiconductor distributed Bragg reflector where the  
5 electric field strength of light is large, and  
wherein said intermediate layer is formed to have a  
reduced thickness and increased impurity doping  
concentration in a region of said semiconductor  
distributed Bragg reflector where the electric field  
10 strength of light is small.

15 72. The surface-emission laser diode as  
claimed in claim 68, wherein said semiconductor  
distributed Bragg reflector has a design reflection  
wavelength of  $1.1\mu\text{m}$  or longer.

20

73. The surface-emission laser diode as  
claimed in claim 68, wherein said active layer  
25 contains a group III element of any or all of Ga and

In and a group V element of any or all of As, N and Sb.

5

74. A surface-emission laser array including a plurality of surface-emission laser diodes each having a semiconductor distributed Bragg reflector,

said semiconductor distributed Bragg reflector comprising:

an alternate stacking of first and second semiconductor layers having respective, different refractive indices; and

a plurality of intermediate layers each sandwiched between a first semiconductor layer and a second semiconductor layer, said intermediate layer having a refractive index intermediate between said refractive indices of said first and second semiconductor layers,

an intermediate layer provided in a region of said semiconductor distributed Bragg reflector having a thickness different from an intermediate layer provided in a different region of said

semiconductor distributed Bragg reflector.

5

75. The surface-emission laser array as  
claimed in claim 74, wherein a difference of bandgap  
between said first and second semiconductor layers is  
set smaller in a region of said semiconductor  
10 distributed Bragg reflector where said intermediate  
layer has an increased thickness than in a region of  
said distributed Bragg reflector where said  
intermediate layer has a reduced thickness.

15

76. The surface-emission laser array as  
claimed in claim 74, wherein said intermediate layers  
20 have different thickness and different doping  
concentrations within said semiconductor distributed  
Bragg reflector, said thickness and doping  
concentration being changed in correspondence to  
electric field strength of light within said  
25 semiconductor distributed Bragg reflector.

77. The semiconductor distributed Bragg reflector as claimed in claim 76, wherein said intermediate layer has an increased thickness and reduced impurity doping concentration in a region of  
5 said semiconductor distributed Bragg reflector where the electric field strength of light is large, and wherein said intermediate layer is formed to have a reduced thickness and increased impurity doping concentration in a region of said semiconductor  
10 distributed Bragg reflector where the electric field strength of light is small.

15

78. The surface-emission laser array as claimed in claim 74, wherein said semiconductor distributed Bragg reflector has a design reflection wavelength of  $1.1\mu\text{m}$  or longer.

20

79. A surface-emission laser module  
25 including a surface-emission laser diode having a



semiconductor distributed Bragg reflector,

said semiconductor distributed Bragg reflector comprising:

an alternate stacking of first and second  
5 semiconductor layers having respective, different refractive indices; and

a plurality of intermediate layers each sandwiched between a first semiconductor layer and a second semiconductor layer, said intermediate layer  
10 having a refractive index intermediate between said refractive indices of said first and second semiconductor layers,

an intermediate layer provided in a region of said semiconductor distributed Bragg reflector  
15 having a thickness different from an intermediate layer provided in a different region of said semiconductor distributed Bragg reflector.

20

80. A surface-emission laser module as claimed in claim 79, wherein said surface-emission laser diode is provided in plural number in the form  
25 of an array.

81. An optical interconnection system including a surface-emission laser diode having a semiconductor distributed Bragg reflector,

said semiconductor distributed Bragg reflector comprising:

an alternate stacking of first and second semiconductor layers having respective, different refractive indices; and

a plurality of intermediate layers each sandwiched between a first semiconductor layer and a second semiconductor layer, said intermediate layer having a refractive index intermediate between said refractive indices of said first and second semiconductor layers,

an intermediate layer provided in a region of said semiconductor distributed Bragg reflector having a thickness different from an intermediate layer provided in a different region of said semiconductor distributed Bragg reflector.

20

82. An optical interconnection system as claimed in claim 77, wherein said surface-emission

25

laser diode is provided in plural number in the form of a surface-emission laser array.

5

83. An optical interconnection system as claimed in claim 81, wherein said surface-emission laser diode forms a surface-emission laser module.

10

84. An optical telecommunication system including a surface-emission laser diode having a semiconductor distributed Bragg reflector, said semiconductor distributed Bragg reflector comprising:

an alternate stacking of first and second semiconductor layers having respective, different refractive indices; and

a plurality of intermediate layers each sandwiched between a first semiconductor layer and a second semiconductor layer, said intermediate layer having a refractive index intermediate between said

25

refractive indices of said first and second  
semiconductor layers,

an intermediate layer provided in a region  
of said semiconductor distributed Bragg reflector  
5 having a thickness different from an intermediate  
layer provided in a different region of said  
semiconductor distributed Bragg reflector.

10

85. An optical interconnection system as  
claimed in claim 84, wherein said surface-emission  
laser diode is provided in plural number in the form  
15 of a surface-emission laser array.

20

86. An optical telecommunication system as  
claimed in claim 84, wherein said surface-emission  
laser diode forms a surface-emission laser module.

25

87. An n-type semiconductor distributed Bragg reflector comprising:

first and second semiconductor layers of n-type stacked with each other, said first and second  
5 semiconductor layers having respective refractive indices different from each other; and

an intermediate layer provided between said first and second semiconductor layers, said intermediate layer having a refractive index  
10 intermediate of said refractive indices of said first and second semiconductor layers.

15

88. An n-type semiconductor distributed Bragg reflector as claimed in claim 87, wherein said intermediate layer has a thickness larger than 20 [nm] in said n-type semiconductor distributed Bragg  
20 reflector.

25

89. An n-type semiconductor distributed

Bragg reflector as claimed in claim 87, wherein said intermediate layer has a thickness equal to or larger than 30 [nm] in said n-type semiconductor distributed Bragg reflector.

5

90. An n-type semiconductor distributed  
10 Bragg reflector as claimed in claim 87, wherein said intermediate layer has a thickness  $t$  [nm] determined with respect to a reflection wavelength  $\lambda$  [um] of said distributed Bragg reflector so as to fall in the ranges of  $20 < t \leq (50\lambda - 15)$  [nm].

15

91. A surface-emission laser diode having  
20 an n-type semiconductor distributed Bragg reflector,  
said n-type semiconductor distributed Bragg reflector comprising:

first and second semiconductor layers of n-type stacked with each other, said first and second  
25 semiconductor layers having respective refractive

indices different from each other; and

an intermediate layer provided between said  
first and second semiconductor layers, said  
intermediate layer having a refractive index  
s intermediate of said refractive indices of said first  
and second semiconductor layers.

10

92. A surface-emission laser diode as  
claimed in claim 91, wherein said intermediate layer  
has a thickness larger than 20 [nm] in said n-type  
semiconductor distributed Bragg reflector.

15

93. A surface-emission laser diode as  
20 claimed in claim 91 wherein said intermediate layer  
has a thickness equal to or larger than 30 [nm] in  
said n-type semiconductor distributed Bragg reflector.

25

94. A surface-emission laser diode as  
claimed in claim 91, wherein said intermediate layer  
has a thickness  $t$  [nm] determined with respect to a  
reflection wavelength  $\lambda$  [um] of said distributed  
5 Bragg reflector so as to fall in the ranges of  $20 < t \leq$   
( $50\lambda - 15$ ) [nm].

10

95. A surface-emission laser diode as  
claimed in claim 91, wherein said active layer is  
formed of a group III element and a group V element,  
said group III element of said active layer being any  
15 or all of Ga and In, said group V element of said  
active layer being any or all of As, N, Sb and P.

20

96. A surface-emission laser diode,  
comprising:  
an active layer;  
an n-type semiconductor distributed Bragg  
25 reflector; and



a p-type semiconductor distributed Bragg reflector,

said n-type semiconductor distributed Bragg reflector and said p-type semiconductor distributed  
5 Bragg reflector being disposed at both sides of said active layer,

wherein said n-type semiconductor distributed Bragg reflector is processed to form a mesa.

10

97. A surface-emission laser diode as  
15 claimed in claim 96, wherein said n-type semiconductor distributed Bragg reflector comprises stacking of first and second semiconductor layers having respective, mutually different refractive indices, said n-type semiconductor distributed Bragg  
20 reflector further comprises an intermediate layer having a refractive index intermediate of said first and second semiconductor layer, between said first and second semiconductor layers.

25

98. A surface-emission laser diode as  
claimed in claim 96, wherein said n-type  
semiconductor distributed Bragg reflector comprises  
stacking of first and second semiconductor layers  
5 having respective refractive indices different from  
each other, said n-type semiconductor distributed  
Bragg reflector further including an intermediate  
layer having a refractive index intermediate of said  
refractive indices of said first and second  
10 semiconductor layers between said first and second  
semiconductor layers with a thick larger than 20 [nm].

15

99. A surface-emission laser diode as  
claimed in claim 96, wherein said n-type  
semiconductor distributed Bragg reflector comprises  
stacking of a first and second semiconductor layers  
20 having respective refractive indices different from  
each other, said n-type semiconductor distributed  
Bragg reflector further including an intermediate  
layer having a refractive index intermediate of said  
first and second semiconductor layers between said  
25 first and second semiconductor layers with a

thickness of 30 [nm] or more.

5

100. A surface-emission laser diode as  
claimed in claim 96, wherein said n-type  
semiconductor distributed Bragg reflector comprises  
stacking of first and second semiconductor layers  
10 having respective refractive indices different from  
each other, said n-type semiconductor distributed  
Bragg reflector further including an intermediate  
layer having a refractive index intermediate of said  
first and second semiconductor layers, between said  
15 first and second semiconductor layers with a  
thickness  $t$  [nm] determined with respect to a  
reflection wavelength  $\lambda$  [um] of said distributed  
Bragg reflector so as to fall in the ranges of  $20 < t \leq$   
( $50\lambda - 15$ ) [nm].

20

101. A surface-emission laser diode as  
25 claimed in claim 96, wherein said active layer is

formed of a group III element and a group V element,  
said group III element of said active layer being any  
or all of Ga and In, said group V element of said  
active layer being any or all of As, N, Sb and P.

5

102. A surface-emission laser diode
- 10 comprising:
- an active layer;
  - an n-type semiconductor distributed Bragg reflector; and
  - a p-type semiconductor distributed Bragg
- 15 reflector, said n-type semiconductor distributed Bragg reflector and said p-type semiconductor distributed Bragg reflector being disposed at both sides of said active layer,
- said n-type semiconductor distributed Bragg
- 20 reflector having an increased resistance with respect to a region forming a cavity of said the surface-emission laser diode.

25

103. A surface-emission laser diode as  
claimed in claim 102, wherein said n-type  
semiconductor distributed Bragg reflector comprises  
stacking of first and second semiconductor layers  
5 having respective, mutually different refractive  
indices, said n-type semiconductor distributed Bragg  
reflector further comprising an intermediate layer  
having a refractive index intermediate of said first  
and second semiconductor layer, between said first  
10 and second semiconductor layers.

15 104. A surface-emission laser diode as  
claimed in claim 102, wherein said n-type  
semiconductor distributed Bragg reflector comprises  
stacking of first and second semiconductor layers  
having respective refractive indices different from  
20 each other, said n-type semiconductor distributed  
Bragg reflector further including an intermediate  
layer having a refractive index intermediate of said  
refractive indices of said first and second  
semiconductor layers between said first and second  
25 semiconductor layers with a thick larger than 20 [nm].

105. A surface-emission laser diode as  
claimed in claim 102, wherein said n-type  
semiconductor distributed Bragg reflector comprises  
stacking of a first and second semiconductor layers  
5 having respective refractive indices different from  
each other, said n-type semiconductor distributed  
Bragg reflector further including an intermediate  
layer having a refractive index intermediate of said  
first and second semiconductor layers between said  
10 first and second semiconductor layers with a  
thickness of 30 [nm] or more.

15

106. A surface-emission laser diode as  
claimed in claim 102, wherein said n-type  
semiconductor distributed Bragg reflector comprises  
stacking of first and second semiconductor layers  
20 having respective refractive indices different from  
each other, said n-type semiconductor distributed  
Bragg reflector further including an intermediate  
layer having a refractive index intermediate of said  
first and second semiconductor layers, between said  
25 first and second semiconductor layers with a

thickness  $t$  [nm] determined with respect to a reflection wavelength  $\lambda$  [um] of said distributed Bragg reflector so as to fall in the ranges of  $20 < t \leq (50\lambda - 15)$  [nm].

5

107. A surface-emission laser diode as claimed in claim 102, wherein said active layer is formed of a group III element and a group V element, said group III element of said active layer being any or all of Ga and In, said group V element of said active layer being any or all of As, N, Sb and P.

15

108. A surface-emission laser array including a surface-emission laser diode, said surface-emission laser diode having an n-type semiconductor distributed Bragg reflector,

said n-type semiconductor distributed Bragg reflector comprising:

25 first and second semiconductor layers of n-

type stacked with each other, said first and second semiconductor layers having respective refractive indices different from each other; and

an intermediate layer provided between said  
5 first and second semiconductor layers, said intermediate layer having a refractive index intermediate of said refractive indices of said first and second semiconductor layers.

10

109. A surface-emission laser array as claimed in claim 108, wherein said intermediate layer  
15 has a thickness larger than 20 [nm] in said n-type semiconductor distributed Bragg reflector.

20

110. A surface-emission laser array as claimed in claim 108, wherein said intermediate layer has a thickness equal to or larger than 30 [nm] in said n-type semiconductor distributed Bragg reflector.

25



111. A surface-emission laser array as  
claimed in claim 108, wherein said intermediate layer  
has a thickness  $t$  [nm] determined with respect to a  
reflection wavelength  $\lambda$  [nm] of said distributed  
5 Bragg reflector so as to fall in the ranges of  $20 < t \leq$   
( $50\lambda - 15$ ) [nm].

10

112. A surface-emission laser array  
including a surface-emission laser diode, said  
surface-emission laser diode, comprising:

an active layer;

15 an n-type semiconductor distributed Bragg  
reflector; and

a p-type semiconductor distributed Bragg  
reflector,

said n-type semiconductor distributed Bragg  
20 reflector and said p-type semiconductor distributed  
Bragg reflector being disposed at both sides of said  
active layer,

wherein said n-type semiconductor  
distributed Bragg reflector is processed to form a  
25 mesa.

113. A surface-emission laser array as  
claimed in claim 112, wherein said intermediate layer  
has a thickness larger than 20 [nm] in said n-type  
semiconductor distributed Bragg reflector.

5

114. A surface-emission laser array as  
10 claimed in claim 112, wherein said intermediate layer  
has a thickness equal to or larger than 30 [nm] in  
said n-type semiconductor distributed Bragg reflector.

15

115. A surface-emission laser array as  
claimed in claim 112, wherein said intermediate layer  
has a thickness  $t$  [nm] determined with respect to a  
20 reflection wavelength  $\lambda$  [um] of said distributed  
Bragg reflector so as to fall in the ranges of  $20 < t \leq$   
 $(50\lambda - 15)$  [nm].

25

116. A surface-emission laser array including a surface-emission laser diode, said surface-emission laser diode comprising:

an active layer;

5 an n-type semiconductor distributed Bragg reflector; and

a p-type semiconductor distributed Bragg reflector, said n-type semiconductor distributed Bragg reflector and said p-type semiconductor distributed Bragg reflector being disposed at both  
10 sides of said active layer,

said n-type semiconductor distributed Bragg reflector having an increased resistance with respect to a region forming a cavity of said the surface-emission laser diode.  
15

20 117. A surface-emission laser module including a surface-emission laser diode, said surface-emission laser diode having an n-type semiconductor distributed Bragg reflector,

said n-type semiconductor distributed Bragg reflector comprising:  
25

first and second semiconductor layers of n-type stacked with each other, said first and second semiconductor layers having respective refractive indices different from each other; and

5           an intermediate layer provided between said first and second semiconductor layers, said intermediate layer having a refractive index intermediate of said refractive indices of said first and second semiconductor layers.

10

118. A surface-emission laser module  
15 including a surface-emission laser diode, said surface-emission laser diode, comprising:

an active layer;

an n-type semiconductor distributed Bragg reflector; and

20           a p-type semiconductor distributed Bragg reflector,

          said n-type semiconductor distributed Bragg reflector and said p-type semiconductor distributed Bragg reflector being disposed at both sides of said  
25 active layer,

wherein said n-type semiconductor distributed Bragg reflector is processed to form a mesa.

5

119. A surface-emission laser module including a surface-emission laser diode, said  
10 surface-emission laser diode comprising:  
an active layer;  
an n-type semiconductor distributed Bragg reflector; and  
a p-type semiconductor distributed Bragg  
15 reflector, said n-type semiconductor distributed Bragg reflector and said p-type semiconductor distributed Bragg reflector being disposed at both sides of said active layer,  
said n-type semiconductor distributed Bragg  
20 reflector having an increased resistance with respect to a region forming a cavity of said the surface-emission laser diode.

25

120. An optical interconnection system including a surface-emission laser diode, said surface-emission laser diode having an n-type semiconductor distributed Bragg reflector, said aid  
5 n-type semiconductor distributed Bragg reflector comprising:

first and second semiconductor layers of n-type stacked with each other, said first and second semiconductor layers having respective refractive  
10 indices different from each other; and

an intermediate layer provided between said first and second semiconductor layers, said intermediate layer having a refractive index intermediate of said refractive indices of said first  
15 and second semiconductor layers.

20 121. An optical interconnection system including a surface-emission laser diode, said surface-emission laser diode, comprising:

an active layer;

an n-type semiconductor distributed Bragg  
25 reflector; and

a p-type semiconductor distributed Bragg reflector,

said n-type semiconductor distributed Bragg reflector and said p-type semiconductor distributed Bragg reflector being disposed at both sides of said active layer,

wherein said n-type semiconductor distributed Bragg reflector is processed to form a mesa.

10

122. An optical interconnection system including a surface-emission laser diode, said surface-emission laser diode comprising:

an active layer;

an n-type semiconductor distributed Bragg reflector; and

a p-type semiconductor distributed Bragg reflector, said n-type semiconductor distributed Bragg reflector and said p-type semiconductor distributed Bragg reflector being disposed at both sides of said active layer,

said n-type semiconductor distributed Bragg

25

reflector having an increased resistance with respect to a region forming a cavity of said the surface-emission laser diode.

5

123. An optical telecommunication system including a surface-emission laser diode, said  
10 surface-emission laser diode having an n-type semiconductor distributed Bragg reflector,  
said n-type semiconductor distributed Bragg reflector comprising:

15 first and second semiconductor layers of n-type stacked with each other, said first and second semiconductor layers having respective refractive indices different from each other; and

an intermediate layer provided between said first and second semiconductor layers, said  
20 intermediate layer having a refractive index intermediate of said refractive indices of said first and second semiconductor layers.

25



124. An optical telecommunication system comprising a surface-emission laser diode, said surface-emission laser diode, comprising:

an active layer;

5 an n-type semiconductor distributed Bragg reflector; and

a p-type semiconductor distributed Bragg reflector,

said n-type semiconductor distributed Bragg  
10 reflector and said p-type semiconductor distributed Bragg reflector being disposed at both sides of said active layer,

wherein said n-type semiconductor distributed Bragg reflector is processed to form a  
15 mesa.

20 125. An optical telecommunication system including a surface-emission laser diode, said surface-emission laser diode comprising:

an active layer;

an n-type semiconductor distributed Bragg  
25 reflector; and

a p-type semiconductor distributed Bragg reflector, said n-type semiconductor distributed Bragg reflector and said p-type semiconductor distributed Bragg reflector being disposed at both  
5 sides of said active layer,

said n-type semiconductor distributed Bragg reflector having an increased resistance with respect to a region forming a cavity of said the surface-emission laser diode.